

THE EFFECTS OF CLIMATE VARIABLES ON THE OUTBREAK OF DENGUE IN QUEENSLAND 2008-2009

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Abstract. Outbreaks of dengue occur in Queensland, Australia nearly every summer. In 2008-2009, there was an unusually large, protracted outbreak of dengue, comprised of 1,200 cases. We investigated the weather variables and their contribution to the 2008-2009 dengue outbreak in Queensland. Case data were obtained from the Communicable Disease Branch of Queensland Health for 2000-2010 for the towns of Cairns and Townsville. Monthly weather data (rainfall, maximum temperature, minimum temperature) and Southern Oscillation Index (SOI) was obtained from the Bureau of Meteorology (BOM). We used a negative binomial model to test associations between these variables and dengue. Lagged models were also created for one, two and three months. Our models suggest all weather variables but not the SOI were associated with dengue in both Cairns and Townsville, without a lag ($p < 0.01$). No significant lag was seen with the weather variables. Rainfall and temperature preceding the 2008-2009 outbreak were also not significantly different ($p < 0.01$) from other years. Short-term (non-lagged) weather variables were associated with the number of dengue cases in Cairns and Townsville. No lag was seen and no association was seen between the SOI and the number of dengue cases, which suggests there may be limited potential to predict large dengue outbreaks using climate variability. The large outbreak in 2008-2009 may have been driven by other, non-weather factors in addition to the immediate weather effect.

Keywords: dengue, climate, outbreak, Queensland, Australia

INTRODUCTION

Dengue infection is a disease spread among humans by the bite of the mosquito vector *Aedes aegypti* (Halstead, 1988). Dengue belongs to the Flavivirus family; there are four different serotypes (Halstead, 1988). Dengue infection is endemic to all tropical countries. Infection usually causes a febrile illness but in severe cases can cause hemorrhage, shock and death (Halstead, 1988).

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Dengue has been found to occur during periods of increased temperature (Chowell and Schez, 2006; Halide and Ridd, 2008; Chen *et al*, 2010), increased humidity (Tipayamongkholgul *et al*, 2009; Chen *et al*, 2010), increased rainfall (Halide and Ridd, 2008; Chen *et al*, 2010) and decreased evaporation (Chowell and Schez, 2006). Outbreaks often occur after a lag of few weeks to a few months from weather variables (Chowell and Schez, 2006; Chen *et al*, 2010). Stochastic studies show weather variables, such as temperature and humidity, influence dengue vector characteristics by affecting the life-cycle of *Aedes aegypti* mosquitoes (Strickman and

Kittayapong, 2002; Barbazan *et al*, 2008; Morales Vargas *et al*, 2010).

Studies from Australia have also linked weather variables with dengue outbreaks (Hu *et al*, 2010). In Australia, dengue occurs in Queensland and the Northern Territory, where the climate is tropical (Russell *et al*, 2009). Australian annual dengue rates are usually around 0-2 per 100,000; however, there have been higher rates in recent years (NNDSS, 2011). Rates in Queensland and the Northern Territory are up to 20 per 100,000 in outbreak years (NNDSS, 2011). Most cases occur between February and May. There is no gender preference for dengue infection and the majority of cases occur in the 15-65 year old age group (NNDSS, 2011).

In this study we examined the associations between a number of weather variables and dengue infection incidence to determine whether an outbreak in 2008-2009 may have been associated with anomalous weather variables. The outbreak took place in Queensland, Australia and was comprised of approximately 1,200 reported cases.

MATERIALS AND METHODS

Ethical approval to conduct the study was obtained from the University of Western Sydney Human Ethics Committee. The following weather data were obtained from the Bureau of Meteorology (BOM) in monthly intervals from 1999-2010 (October 2010): rainfall, mean maximum temperature and mean minimum temperature and the Southern Oscillation Index (SOI). These variables were used because other studies had linked these variables with dengue infection outbreaks.

Data regarding dengue outbreaks was obtained from the Communicable Disease Branch of Queensland Health for 2000-

2010 (earliest reliable records to present). There were 3,301 notified cases of dengue during that period. Line record data included the following variables: month and year of infection, age group of the patient (0-14, 14-64, 65+ years), sex of the patient, place of acquisition (overseas or locally) and health service district [Townsville, Cairns and Hinterland (henceforth referred to as Cairns), and other].

Of the 3,301 cases, those contracted outside Townsville and Cairns and those acquired overseas were eliminated from this study. The remainder were comprised of 1,868 cases, 1,601 of these occurred in Cairns and 267 occurred in Townsville. During 2008-2009 there were 1,200 local acquired dengue cases in Queensland, of whom 964 were from Cairns and 108 were from Townsville.

Population estimates for the years 2000-2010 were obtained for the Cairns and Townsville health service districts (dengue data is recorded by health district). A population growth rate of 1.48% per annum (Harper *et al*, 2004) was reported for Townsville and 3% per annum for Cairns (Queensland Health, 2011).

The data from 2000 - 2010 were analyzed to determine yearly and monthly trends for weather, dengue cases, sex differences, age distribution and by location (Townsville and Cairns). The data for 2008-2010 (the period of the dengue outbreak) were analyzed for trends.

SPSS was used to create negative binomial models for the interaction between weather variables (rainfall, minimum and maximum temperature and SOI) and dengue infections for 2000-2010. Another model was created to determine the relationship between dengue cases and the combined effect of rainfall and maximum temperature. Lag models were created by lagging the weather variable by one, two

or three months from the dengue data.

RESULTS

Weather data

Looking at the rainfall and temperature trends for 1999-2010 (Fig 1a and 1b), there were yearly peaks between November and February. There was an increasing trend in rainfall but not temperature over the years. There was an especially prominent peak in rainfall in 2009, which coincided with the current outbreak of interest.

Southern Oscillation Index

As expected the SOI data variation was cyclic (Fig 2). There were prolonged periods of both positive and negative variations in the SOI often over periods greater than one year; however, there was no fixed pattern observable.

Dengue data

There were 1,868 cases of dengue reported during 2000-2010 with 1,601 occurring in Cairns and 267 in Townsville. Of the 1,601 cases, 885 were female, 981 were male and in 2 cases the sex was not reported. The difference between sexes was statistically significant ($p < 0.01$). In terms of age, the 15-64 year old age group had the greatest number of cases.

When plotting the rate of dengue by year per 100,000 population (Fig 3), there were two apparent outbreaks, one in 2003

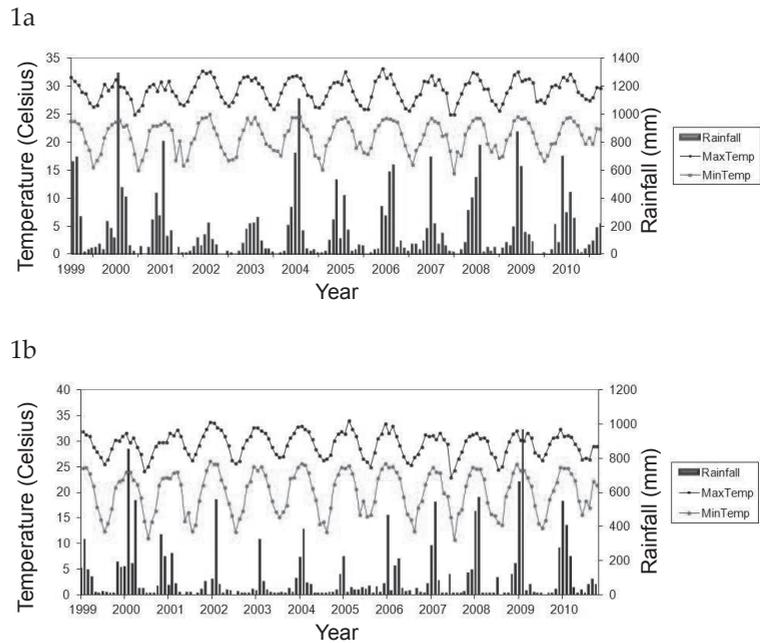


Fig 1—Monthly climate data: (1a) for Cairns during 1999-2010 and (1b) for Townsville during 1990-2010.

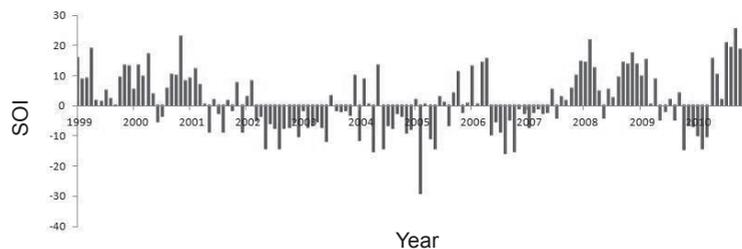


Fig 2—Southern Oscillation Index for 1999-2010.

and one in 2009. Dengue was less prevalent in Townsville. During 2000-2010, most dengue cases occurred between January and March, very few cases occurred between June and November. This coincided with the peaks in rainfall and temperature mentioned above.

During the dengue outbreak of 2008-2010, 964 cases were reported from Cairns and 108 from Townsville (Fig 4). The peak

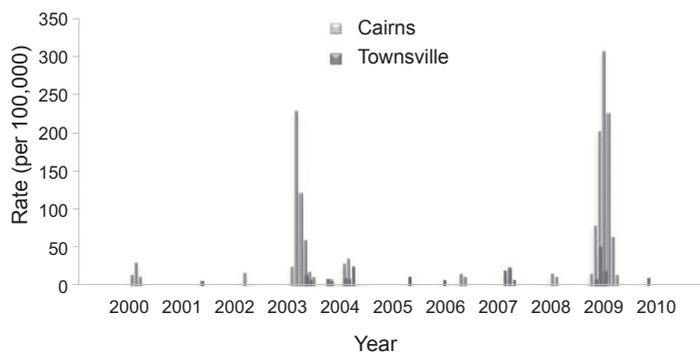


Fig 3—Monthly rate of dengue during 2000-2010.

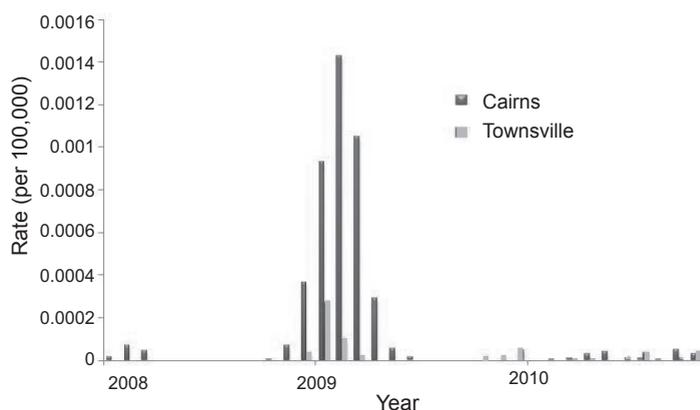


Fig 4—Monthly rates of dengue infection during 2008-2010.

in the number of dengue cases and in rainfall both occurred between January and March each year.

Table 1 shows the rainfall and temperature for 2008-2009 compared to the data for 2000-2010. There were no statistically significant differences ($p < 0.01$) between the data.

The relationship between dengue infections and weather

Tables 2-6 summarize the results of the negative binomial models. The variables rainfall, maximum temperature and minimum temperature were significantly correlated ($p < 0.01$) with dengue incidence in both Cairns and Townsville when there was no lag in weather data. There was a

significant association between the SOI and dengue incidence for Cairns ($p < 0.01$) but not for Townsville.

When adding a lag time to the model, rainfall was significantly associated with dengue incidence in Cairns at 1 month and in Townsville at 3 months. The maximum temperature was significantly associated with dengue incidence without lag and with lag times of 1, 2 and 3 months for Cairns and with a lag time of 1 month for Townsville. The minimum temperature was associated with dengue incidence without lag and with a lag time of 1 month at Cairns and without a lag time and with lag times of 2 and 3 months at Townsville. The SOI was associated with dengue incidence with no lag at Cairns and with a lag time of 3 months at Townsville.

DISCUSSION

The current study aimed to determine whether the 2008-2009 dengue outbreak in Queensland, could be attributed to weather factors. Between 2000 and 2010 there were 3,301 dengue cases in Queensland with 1,868 occurring in Townsville and Cairns. During the outbreak in 2008-2009 there were 1,172 dengue cases in Townsville and Cairns.

Using negative binomial models, the monthly incidence of dengue was correlated with rainfall, maximum temperature, minimum temperature and SOI and the combined effect of rainfall and maximum temperature. The weather variables were also lagged 1, 2 and 3 months to

Table 1
Weather data for 2008-2009 compared to the data for 2000-2010.

| | 2008/2009 difference to remaining data | <i>p</i> -value | 95% Confidence interval (low CI, high CI) |
|---------------------|---|-----------------|--|
| Cairns | | | |
| Maximum temperature | 0.54 degrees | 0.040 | -0.52, 0.61 |
| Minimum temperature | 0.25 degrees | 0.230 | -0.53, 0.53 |
| Rainfall | 13.11 mm | 0.850 | -204.12, 54.60 |
| Townsville | | | |
| Maximum temperature | -0.05 degrees | 0.863 | 0.03, 1.06 |
| Minimum temperature | -0.01 degrees | 0.997 | -0.70, 0.19 |
| Rainfall | 74.76 mm | 0.230 | -162.04, 135.82 |

Table 2
Association between rainfall and dengue incidence with and without lagging.

| | <i>p</i> -value | Exp(B) (low CI, high CI) |
|------------------|-----------------|--------------------------|
| Cairns | | |
| No lag time | 0.000 | 1.030 (1.020, 1.040) |
| Lag time 1 month | 0.000 | 1.000 (0.999, 1.000) |
| 2 months | 0.369 | 1.000 (1.000, 1.000) |
| 3 months | 0.038 | 0.999 (0.998, 1.000) |
| Townsville | | |
| No lag time | 0.003 | 1.020 (1.010, 1.030) |
| Lag time 1 month | 0.102 | 1.010 (1.000, 1.020) |
| 2 months | 0.029 | 0.999 (0.997, 1.000) |
| 3 months | 0.000 | 0.996 (0.994, 0.998) |

Table 3
Association between maximum temperature and dengue incidence with and without lagging.

| | <i>p</i> -value | Exp(B) (low CI, high CI) |
|------------------|-----------------|--------------------------|
| Cairns | | |
| No lag time | 0.000 | 1.559 (1.420, 1.711) |
| Lag time 1 month | 0.005 | 0.834 (0.735, 0.946) |
| 2 months | 0.000 | 0.743 (0.648, 0.853) |
| 3 months | 0.000 | 0.750 (0.662, 0.851) |
| Townsville | | |
| No lag time | 0.000 | 1.245 (1.111, 1.396) |
| Lag time 1 month | 0.693 | 0.980 (0.885, 1.084) |
| 2 months | 0.004 | 0.881 (0.809, 0.960) |
| 3 months | 0.000 | 0.753 (0.682, 0.831) |

Table 4
Association between minimum temperature and dengue incidence with and without lagging.

| | <i>p</i> -value | Exp(B) (low CI, high CI) |
|------------------|-----------------|--------------------------|
| Cairns | | |
| No lag time | 0.000 | 1.531 (1.407, 1.665) |
| Lag time 1 month | 0.000 | 1.125 (1.059, 1.195) |
| 2 months | 0.184 | 0.936 (0.849, 1.032) |
| 3 months | 0.682 | 1.013 (0.953, 1.077) |
| Townsville | | |
| No lag time | 0.000 | 0.812 (0.732, 0.902) |
| Lag time 1 month | 0.005 | 0.926 (0.877, 0.977) |
| 2 months | 0.000 | 0.804 (0.724, 0.892) |
| 3 months | 0.000 | 0.854 (0.825, 0.884) |

Table 5
Association between Southern Oscillation Index and dengue incidence with and without lagging.

| | <i>p</i> -value | Exp(B) (low CI, high CI) |
|------------------|-----------------|--------------------------|
| Cairns | | |
| No lag time | 0.000 | 1.054 (1.033, 1.075) |
| Lag time 1 month | 0.550 | 0.994 (0.974, 1.014) |
| 2 months | 0.491 | 1.008 (0.985, 1.033) |
| 3 months | 0.123 | 1.018 (0.995, 1.040) |
| Townsville | | |
| No lag time | 0.765 | 0.996 (0.974, 1.020) |
| Lag time 1 month | 0.604 | 0.994 (0.97, 1.017) |
| 2 months | 0.689 | 0.995 (0.971, 1.019) |
| 3 months | 0.000 | 0.843 (0.794, 0.895) |

Table 6
Association between rainfall and maximum temperature and dengue incidence with and without lagging.

| | <i>p</i> -value | Exp(B) (low CI, high CI) |
|------------------|-----------------|--------------------------|
| Cairns | | |
| No lag time | 0.000 | 1.000 (1.000, 1.000) |
| Lag time 1 month | 0.003 | 1.000 (1.000, 1.000) |
| 2 months | 0.369 | 1.000 (1.000, 1.000) |
| 3 months | 0.117 | 1.000 (1.000, 1.000) |
| Townsville | | |
| No lag time | 0.003 | 1.000 (1.000, 1.000) |
| Lag time 1 month | 0.019 | 1.000 (1.000, 1.000) |
| 2 months | 0.038 | 1.000 (1.000, 1.000) |
| 3 months | 0.000 | 0.778 (0.703, 0.860) |

determine if any of the weather variables were associated with an increase in dengue incidence. Peaks in dengue were seen in the summer, during January to March. Rainfall and temperature peaks were seen during November to March.

The 2008-2009 weather data did not differ significantly from the other years. Using a negative binomial model looking at the data during 2000-2010, all weather variables correlated significantly ($p < 0.01$) with dengue incidence except the SOI in Townsville, when there was no lag in weather data. Several relationships were noted in the lagged models; however no consistent patterns were present. The current study adds to the growing evidence that dengue occurs in warm and humid climates.

Similar studies of dengue incidence, outbreaks and weather variables have been conducted over the past ten to fifteen years. In the current study, rainfall was significantly correlated with dengue incidence without a lag in both Cairns and Townsville. Rainfall has also been found to correlate with dengue without a lag period in other studies (Chowell and Sacherz, 2006; Hurtado-Diaz *et al*, 2007; Jury, 2008; Diaz-Quijano *et al*, 2008). Stochastic studies have also shown that the dengue vector, *Aedes aegypti* proliferates in wet conditions (Chadee, 2009).

However, when studying the effect of a lag on dengue incidence and rainfall, the only significant correlation ($p > 0.01$) was at one month in Cairns and at three months in Townsville. In other studies a correlation was seen with a lag time of five to twenty weeks (Hii *et al*, 2009), seven weeks (Depradine and Lovell, 2004), three months (Chen *et al*, 2010), one to six months (Halide and Ridd, 2008), and at one and two months (Johansson *et al*,

2009). However, correlation was most significant with no lag time, similar to other studies (Hurtado-Diaz *et al*, 2007; Jury, 2008; Diaz-Quijano *et al*, 2008).

Both minimum and maximum temperatures were significantly correlated with dengue incidence without a lag in our study. Maximum and minimum temperatures were also correlated with dengue incidence without a lag time in another study (Chowell and Sacherz, 2006). Other studies have looked at average temperature (instead of maximum and minimum temperature) and have also found a correlation with dengue incidence without a lag (Bangs *et al*, 2006; Hurtado-Diaz *et al*, 2007; Dibo *et al*, 2008; Johansson *et al*, 2009). These studies are similar to our study in that they looked at monthly data for temperature and dengue incidence despite looking at average temperature. Further studies show temperature is important in mosquito size and in the egg to larvae cycle (Strickman and Kittayapong, 2002). Rainfall and temperature are important factors affecting dengue incidence.

Maximum temperature was significantly associated with dengue incidence for all lag times of one, two and three months for both Cairns and Townsville except with a lag time of one month in Townsville and minimum temperature was significantly associated with dengue incidence for all lag times of one, two and three months in Townsville and for one month in Cairns. In other studies, minimum temperature has been found to be significant at one month (Chowell and Sacherz, 2008) and four to fifteen weeks (Depradine and Lovell, 2004). A maximum temperature has been found to be significant at lag time of three to twelve weeks (Depradine and Lovell, 2004). Average temperature was found to be significant

with a lag time of three months (Chen *et al*, 2010), one to six months (Halide and Ridd, 2008), and at one and two months (Johansson *et al*, 2009). For weekly data, temperature was found to be significant at a lag time of five to sixteen weeks (Hii *et al*, 2009). It can be concluded that temperature is an important factor associated with dengue incidence, but there is significant variation in the lag time. This suggests short term weather variables are important in predicting outbreaks of dengue, but long term changes in climate cannot always predict outbreaks of dengue.

There was no consistent relationship between dengue incidence and the SOI. The SOI was only significant in Cairns with no lag time and in Townsville with three months lag time. Other studies have evaluated different indicators for the El Niño Southern Oscillation (ENSO) instead of the SOI. Unlike the current study, the relationship between ENSO and dengue incidence has been shown to be stronger (Hales *et al*, 1999; Cazelles *et al*, 2005) with a lag of sixteen to twenty weeks (Hurtado-Diaz *et al*, 2007; Diaz-Quijano *et al*, 2008) and one to eleven weeks (Tipayamongkholgul *et al*, 2009). A decrease in the SOI (*ie*, warmer conditions over Australia) has been associated with increases in monthly dengue cases with a lag time of three to twelve months in Queensland (Hu *et al*, 2010). That study is similar to our study, in that they collected the monthly SOI from the BOM and the monthly dengue incidence; however, the lag period in their study was greater than in our study. Perhaps in our study, the SOI lag time was not sufficient to determine the relationship between dengue and SOI. Only one study found the link between ENSO and dengue to be weak (Johansson *et al*, 2009).

The combined effect of rainfall and maximum temperature was found to

be significantly associated with dengue incidence in both Cairns and Townsville without a lag time and with a one month lag time, but was also significant in Townsville at a lag of three months. Most other studies have not looked at the combined effect of temperature and rainfall. It is possible that dengue occurs during periods of increased rainfall but only with increased temperature. Looking at different lag times for different weather variables may be a way to determine the strongest relationship between dengue and weather.

The 2008-2009 weather variables were not significantly different ($p < 0.01$) from previous years. This suggests that although the dengue outbreak of interest occurred in the warmer months of the year we cannot say longer term climate changes were responsible for this outbreak. Weather variables are important for driving dengue outbreak, but other factors may have contributed to this outbreak.

One limitation of our study was that it used population estimates in our negative binomial model, since exact estimates were unavailable. The retrospective nature of the study was also a limitation; however the majority of studies in this field use retrospective data due to long time frames. Future studies may be improved by varying temperature, rainfall and SOI further lag times.

In summary, anomalies in weather variables are important for causing increases in dengue incidence. Weather changes precede dengue outbreaks by only short periods of time (one to three months). Although, there were no significant differences between the 2008-2009 weather variables and the other years which could account for the outbreak, our results suggests an overall relationship between weather anomalies and dengue

incidence. Being aware of this is important to curb outbreaks of dengue before they arise. Other causes of dengue outbreak also need to be studied to determine the exact dynamics of dengue outbreaks.

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